

REMARKS

By the present amendment, claims 1 to 16 are pending in the application.

Claim 1 is the only independent claim.

Claim Amendment

Support for the amendment to claim 1 may be found in the specification, e.g., at page 18, lines 10 to 18 which discloses that the slag is formed on the molten silicon.

§103

Claims 1 to 16 were rejected under 35 U.S.C. §103(a) as being unpatentable over U.S. Patent Pub. No. 2005/0139148 to Fujiwara et al.

This rejection, as applied to the amended claims, is respectfully traversed.

U.S. Patent Pub. No. 2005/0139148 is derived from PCT/JP2003/01803 which was published as WO 03/066523 on August 14, 2003. WO 03/066523 was cited in an Information Disclosure Statement.

The Present Invention

The present invention provides a method for removing boron from silicon characterized by heating metal silicon containing boron as an impurity to its melting point to 2200°C to place it in a molten state, then adding a solid mainly comprised of silicon dioxide (hereinafter referred to as a “solid having a main component of SiO₂”) and a solid mainly comprised of one or both of a carbonate of an alkali metal or a hydrate of a carbonate of an alkali metal (herein after referred to as a “solid having a main component of Na₂CO₃ or the like”) into the molten silicon so as to form a slag on the molten silicon and remove the boron from the silicon.

The method of the present invention is summarized by the steps as follows:

(A) placing the metallic silicon containing boron into the molten state,

(B) then adding the “solid having a main component of SiO_2 ” and the “solid having a main component of Na_2CO_3 or the like” into the molten silicon,

(C) thereby forming a slag on the molten silicon, and

(D) removing boron from the silicon.

That is, the method of the present invention is characterized by making metallic silicon containing boron into a molten state, then adding the solid having a main component of SiO_2 and the solid having a main component of Na_2CO_3 or the like to the molten silicon (without making them into a slag state in advance) so as to form a slag on the molten silicon for the first time, and remove the boron from the silicon.

As understood from the descriptions on page 14, line 32 to page 15, line 7 and on page 16, lines 5 to 12 of the specification, according to the above procedure of the present invention, as more boron is absorbed into the slag from the molten silicon, the distribution coefficient of boron in the slag becomes as high as 5 or more and actions are caused to accelerate the effect of vaporizing boron.

Further, according to the above procedure, actions are caused wherein the distribution coefficient of boron becomes higher as the B concentration in the molten silicon becomes lower and the distribution coefficient of boron becomes extremely higher than 10 when the B concentration in the molten silicon falls to 1 mass ppm or so.

Because of the above actions, an excellent effect results wherein the boron concentration in the molten silicon can be reduced to 0.3 mass ppm or less and further to 0.1 mass ppm or less.

Specifically, in the Examples of the present invention, extremely low boron concentrations such as 0.29 mass ppm in sample 2 of Example 1 (page 22) and 0.06 mass ppm in Example 2 (page 24) were realized.

Patentability

U.S. Patent Pub. No. 2005/0139146 ("US '148")

US '148 relates to a silicon purifying method and discloses a method comprising: maintaining raw silicon containing boron and slag in a molten state, stirring the molten silicon and slag, absorbing boron in the slag, and thereby reducing boron in the silicon.

US '148 discloses a mixture of SiO_2 and CaO as slag material and discloses that the slag material is melted together with the raw silicon in a crucible and processed.

US '148 also discloses that Al_2O_3 , MgO , BaO or CaF_2 may be added to control the melting point and viscosity, and that preferably a part or all of the CaO may be replaced by alkaline metal oxides such as Li_2O , Na_2O , and further that Li_2CO_3 , LiHCO_3 , Li_2SiO_4 , Na_2CO_3 , NaHCO_3 , and Na_2SiO_4 are preferably used in place of the alkaline metal oxides.

Difference between the present invention and US '148

As explained above, the technology of US '148 is a method comprised of charging the raw silicon together with the slag material in a crucible, then melting them together.

When SiO_2 and CaO are used as the slag material, the raw silicon is melted first, then a slag comprised of SiO_2 and CaO is formed.

However, when SiO_2 and one or more of Li_2CO_3 , LiHCO_3 , Li_2SiO_4 , Na_2CO_3 , NaHCO_3 and Na_2SiO_4 are used as the slag material, since the slag ($\text{Li}_2\text{O} \cdot \text{SiO}_2$ slag or $\text{Na}_2\text{O} \cdot \text{SiO}_2$ slag) is formed first and then the silicon is melted, an effect and an action increasing the distribution coefficient of boron cannot be obtained.

Attached hereto are phase diagrams of the binary system of $\text{Li}_2\text{O} - \text{SiO}_2$ and $\text{Na}_2\text{O} - \text{SiO}_2$, respectively.

In both phase diagrams, it is understood by one skilled in the art that the slag is almost in a state of a liquid phase at the 1414°C melting point of silicon and that although Tridymite is formed at 90% or more of the Si_2 concentration, the liquid phase still exists and the slag melts in advance of the silicon.

On the contrary, in the present invention, the solid having a main component of SiO_2 and the solid having a main component of Na_2CO_3 or the like are added (without making them into slag in advance) to the molten silicon, and then a slag is formed on the molten silicon for the first time. Therefore, it is possible to increase the distribution coefficient of boron to 5 or more and accelerate the vaporizing action of boron.

Absorption of boron into the slag is an action caused by the generation of boron oxide by oxidizing the boron. It is well known that the oxidation potential is relatively large in Na_2CO_3 and is small in $\text{Na}_2 \cdot \text{SiO}_2$ and SiO_2 .

Therefore, it is considered that the distribution coefficient is high in the present invention where Na_2CO_3 is added as it is, i.e., as solid.

It is believed that the vaporization of boron is caused by generation of $\text{Na}_2\text{O} \cdot \text{B}_2\text{O}_3$ (=2 NaBO_2 : page 15, lines 24 to 29, page 19, lines 13 to 20).

It is also believed that separate Na_2O generated from Na_2CO_3 has a greatly higher reactivity than Na_2O in $\text{Na}_2\text{O} \cdot \text{SiO}_2$ of the slag, easily reacts with boron in the molten silicon and it is easy to form $\text{Na}_2\text{O} \cdot \text{B}_2\text{O}_3$.

Therefore, it is believed that the vaporization of boron is accelerated in the present invention where Na_2CO_3 is added.

As explained above, not only procedure but also the action on the boron of the present invention are greatly different from those of US '148.

Because of the difference of the procedure and the actions, the technology of US '148 reduces boron concentration in the silicon to 0.3 mass ppm (Example 7) at lowest,

while the present invention greatly reduces boron concentration in the silicon to, e.g., 0.06 mass ppm (Example 2).

As explained above, the procedures and actions of the present invention are different from those of US '148. As a result, the present invention exhibits an excellent effect reducing the boron concentration in the silicon to 0.1 mass ppm or less.

US '148 does not disclose or suggest the present invention.

It is therefore submitted that claims 1 to 16 are patentable over US '148.

Attachment

Phase Diagrams For Ceramics, American Ceramic Society, Inc. 1964: Figs. 182 ($\text{Li}_2\text{O} - \text{SiO}_2$) and 192 ($\text{Na}_2\text{O} - \text{SiO}_2$).

Foreign Priority

The present application claims foreign priority under 35 U.S.C. §119 from Japanese Patent Application No. 2004-059156 filed March 3, 2004. See Inventors Declaration.

It is respectfully requested that the claim to foreign priority under 35 U.S.C. §119 and receipt of a certified copy of the priority document be acknowledged in the next communication from the Patent and Trademark Office.

CONCLUSION

It is submitted that in view of the present amendment and foregoing remarks, the application is now in condition for allowance. It is therefore respectfully requested that the application, as amended, be allowed and passed for issue.

Respectfully submitted,

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PHASE DIAGRAMS FOR CERAMISTS

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Compiled at the National Bureau of Standards



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1964

$\text{Li}_2\text{O}-\text{SiO}_2$

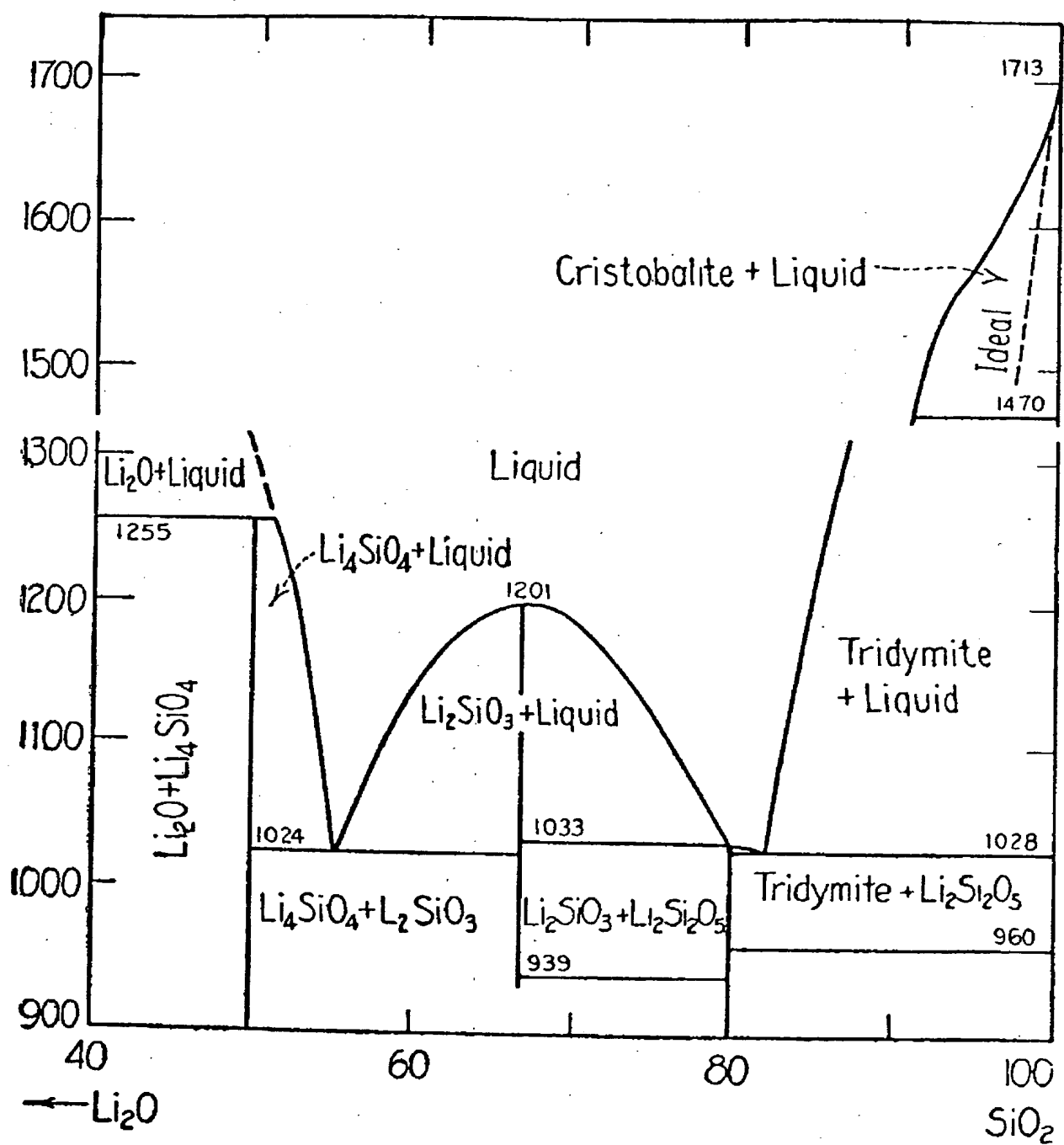


FIG. 182.—System $\text{SiO}_2-2\text{Li}_2\text{O} \cdot \text{SiO}_2$.

F. C. Kracek, *J. Phys. Chem.*, 34, Part II, 2645 (1930).

$\text{Na}_2\text{O}-\text{SiO}_2$

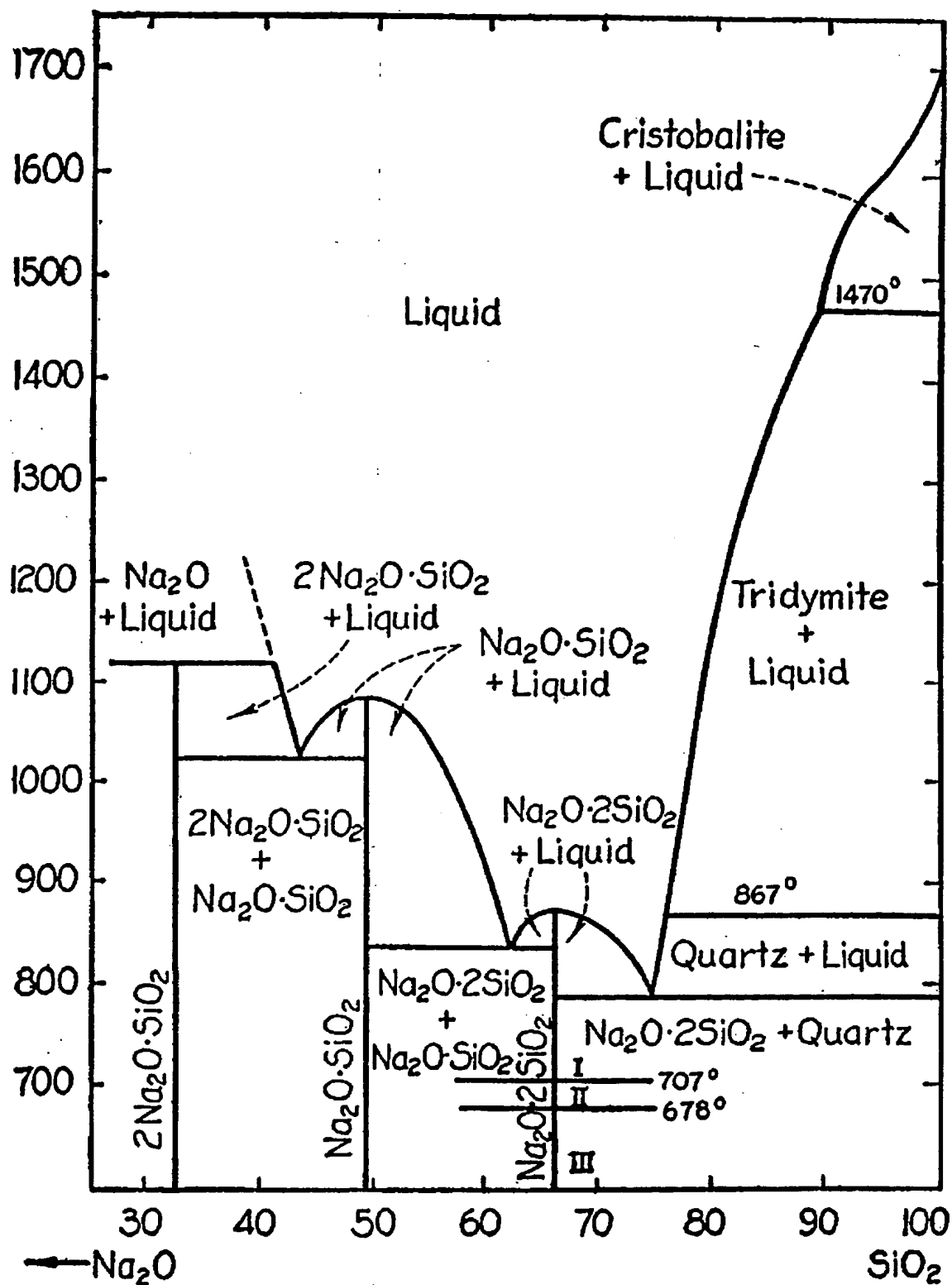


FIG. 192.—System $\text{SiO}_2-2\text{Na}_2\text{O}\cdot\text{SiO}_2$.

F. C. Kracek, *J. Phys. Chem.*, 34, 1588 (1930); *J. Am. Chem. Soc.*, 61, 2869 (1939).